

Balance Perturbation System to Improve Balance Compensatory Responses During Walking in Elderly Persons

Amir Shapiro¹, Itshak Melzer²

¹ Department of Mechanical Engineering, Faculty of Engineering, Ben-Gurion University of the Negev, Beer-Sheva, Israel, e-mail: ashapiro@bgu.ac.il

² Department of Physical Therapy, Faculty of Health Sciences, Ben-Gurion University of the Negev, Beer-Sheva, Israel, e-mail: itzikm@bgu.ac.il

Correspondence address

Itzik Melzer PhD PT

Schwartz Movement Analysis & Rehabilitation Laboratory

Department of Physical Therapy, Recanati School for Community Health Professions

Faculty of Health Sciences

Ben-Gurion University of the Negev

P.O.B. 653, Beer-Sheva 84105, Israel

Tel. +972 (0)8 647-7727. Fax +972 (0)8 647-7683

e-mail: itzikm@bgu.ac.il

ABSTRACT

Ageing commonly disrupts the balance control and compensatory postural responses that contribute to maintaining balance and preventing falls during perturbation of posture. This can lead to increased risk of falling in old adults (65 years old and over). Therefore, improving compensatory postural responses during walking is one of the goals in fall prevention programs. Training is often used to achieve this goal. Most fall prevention programs are usually directed towards improving voluntary postural control and thus are able to improve compensatory postural responses. Since compensatory postural responses triggered by a slip or a trip are not under direct voluntary control they cannot be trained through voluntary exercises.

This paper describes the Balance Measure & Perturbation System (BaMPer System) a system that provides small, controlled and unpredictable perturbations during treadmill walking providing valuable perturbation, which allows to train their compensatory postural responses during walking which thus hypothesize to improve “recovery reflexes” in older adults.

Key words: Ageing, anticipatory postural adjustments, compensatory postural responses, Perturbation.

Postural control is the foundation of our ability to move independently. Acute injuries, including traumatic brain and spinal cord injuries, Hip fracture and even death occurring as a result of falls in old adults [1]. In the older adults about one out of three individuals fall [2]. Falls are the leading cause of accidental death in the elderly population [3]. The cost has been estimated to be nearly \$10 billion for one year [4–6]. Consequently, there is a need to develop new technologies that will improve interventions for reducing falls and increasing quality of life in older adults.

The benefits of exercise with respect to general health, strength, and balance have been long documented in the physical exercise literature [7–16]. However, research studies investigating exercise as a means of falls prevention in older adults have shown controversial results. Several studies show that exercise prevents falls [17–22] and other studies have shown no reduction in falls [23–25]. The controversial results may be the result of the flaw in many balance training programs ignoring a basic principle of physical training, the concept of specificity. The majority of falls occurs during walking [26] and results from unexpected perturbations. In spite of this, most balance training regimens only include voluntarily controlled exercises that do not include perturbation exercises that improve compensatory postural responses during walking, which may improve the ability to prevent falling when a person loses his/her balance. The postural responses triggered by a slip or a trip are not under direct voluntary control [27–29]. These postural “reflexes”, initiated by external postural perturbations, lead to activation of specific recovery strategies. These recovery strategies are not under volitional control and thus cannot be trained through voluntary exercises; they must be trained specifically through unexpected external perturbation exercises during walking.

Wolfson et al. [30] were able to demonstrate improvements in balance function in old adults using a balance-specific intervention that included perturbation exercises. Oddsson et al. [31] proposed a specific training program that involves use of unpredictable, multi-directional perturbations to evoke stepping responses in elderly persons. Mansfield et al. [32] used of a perturbation platform that moves suddenly and unpredictably in one of four directions as part of a balance training program. Rogers et al. [33] showed that either voluntary or waist-pull-induced step training reduced step initiation time. The above-mentioned studies [30, 32, 33] train compensatory responses during up-right standing and not during walking, thus training effects should not be expected.

System Description

The Balance Measure and Perturbation System (BaMPer System) that triggers postural “reflexes” to improve balance responses is designed to supply the patient with an unexpected acceleration during regular treadmill walking. The acceleration can be applied in any direction in the plane and with a maximum magnitude of 10 m/s^2 . This maximal acceleration was chosen because it is the maximal falling acceleration. The system is composed of a regular treadmill mounted on a moving platform, motion controller, and an operator station (Figure 1). The moving platform is mounted on linear slides, which allow it to translate in any direction in the plane. Two linear actuators are responsible for moving the platform longitudinally, laterally, or any combination of those directions. The motion controller controls the motion of the two motors such that the motion is along the trapezoidal velocity profile (i.e., accelerating, moving at a constant velocity, decelerating). The operator’s station serves as the user interface of the system and provides the therapist

with the ability to control all training parameters including maximal acceleration, number of repetitions, and time intervals. The computer also saves a log file of the training protocol for future use.

A. Hardware

The hardware of the system includes the following components: treadmill, moving platform, linear slides, linear actuators, and ball rollers. The uncovered BaMPer system with the treadmill removed is shown in Figure 2.

The moving platform is mounted on four sliding mechanisms to allow motion in both longitudinal and lateral directions. Each of the four sliding mechanisms is composed of three linear slides mounted in an H-like shape. For the linear slides we selected the ABBA BRH30BL slides. Each of the two driving units is composed of an AC servo motor connected through a coupler to a ball screw. The nut of the ball screw is connected through a linear slide to the moving frame. The reason for the additional linear slide between the nut and the frame is that the frame can be moved perpendicularly by the other drive unit. For the drive unit, we used the Rockwell Automation MPL-A330P-HJ22AA, AC servo motor, with 1800 W power, maximal speed of 5000 rpm, and peak torque of 11.1 Nm. The coupler is the Huco flexible coupling p/n 670.52.42.40 that is capable of transferring the required torque. The ball drive unit is the Kuroda GG2510DS-BALR-0533C-C5S accompanied with a supporting BUK20A bearing unit. The linear slide that is between the nut and the moving frame is the ABBA BRH25BL.

B. Motion Control

The motion control system is based on the ACS SPiiPlus-CM controller. In our system the host PC serves as a user interface and as a high level programming environment. The control architecture is described in Figure 3.

The control program, which will be described hereafter, uses the SpiiPlus Com Library to communicate with the SpiiPlus CM-2-BE-MO two-axis motion controller and brushless motor drivers. Communication between the PC and the controller is simple RS232 serial communication. The controller receives from the PC program the required motion parameters, which are the target position, maximal velocity, acceleration, and deceleration. The controller has an internal motion profile generator that generates a trapezoidal velocity profile. In our case, where acceleration is the important parameter, we use a triangular velocity profile where the platform accelerates in order to generate the required perturbation, and then decelerates to zero velocity. The controller has a real time CPU that controls the motion using PID control law. The internal driver sends current commands to the motors, and the controller receives position feedback from optical encoders mounted on the back of each motor. Graphs of the position, velocity, and acceleration during perturbation experiments are shown in Figure 4.

C. Software Design and User Interface

The program that serves as the system's user interface is written in Microsoft Visual Basic 2008 and runs on the host PC. The application is a Windows form application and contains four tabs: communication, setting parameters, testing, and run experiment.

Communication tab: The communication tab allows opening and closing the communication port to the ACS controller. It also reminds the operator to check if the safety harness is secured. In addition, it automatically calibrates the travel range of each of the motors and moves the platform into the home position at the center of the working range. A snapshot of the communication tab of the perturbation control application is shown in Figure 5.

Set Parameters tab: this tab enables changing the minimal and maximal values of the motion profile parameters. It also enables setting the number of perturbations during a single experiment or training series, and the time delay between two consecutive perturbations. For each perturbation to be executed the system will randomly select each parameter within the range specified by the minimal and maximal values. A snapshot of the parameters setting tab is shown in Figure 6.

Testing tab: This tab allows applying a single perturbation in a manually selected direction. A snapshot of the testing tab is shown in Figure 7.

Run Experiment tab: This tab is the most important one, since from here the operators actually starts the training sequence in which a series of perturbations will be applied to the patient. The tab presents several items, first are the start and stop buttons for starting the training or stopping it. Then there is the number of current perturbations within the series (initial value is zero), and the total time left for the current run. The operator can provide a filename for a log file that contains the run parameters. On the right there is a box that will contain a graph of the platform velocity during the perturbation interval. On the bottom there is a table containing all the motion parameters that have been randomly selected for the

perturbation executed. A snapshot of the Run Experiment tab is shown in Figure 8.

D. Safety

Safety is an extremely important issue since we apply perturbation to an older patient walking and that may cause him or her to fall. To prevent any injury during a fall, the patient is wearing a safety harness that will arrest the fall before the patient's knees touch the ground. Examples of such a safety harness are the Skylotec G-0904 or the PN12 harness. The safety harness is hung from the ceiling by two threads above the patients. However, for stability reasons the threads do not hang straight from the ceiling, but in a diagonal such that the distance between the connection points of the two threads on the ceiling is about 2m.

COMPETING INTERESTS

None

AUTHORS' CONTRIBUTIONS

IM and AS was involved in planning the BaMPer system as well as drafting of the manuscript and have both given final approval of the current manuscript.

REFERENCES

1. Masud T, Morris RO: **Epidemiology of falls.** *Age Ageing* 2001, **30**:3-7.
2. Tinetti ME, Speechley M, Ginter SF: **Risk factors for falls among elderly persons living in the community.** *N Engl J Med* 1988, **319**(26):1701-1707.
3. Centers for Disease Control and Prevention (CDC). Fatalities and injuries from falls among older adults--United States, 1993-2003 and 2001-2005. *MMWR Morb Mortal Wkly Rep.* 2006; 55(45):1221-4. Available at <http://www.cdc.gov/mmwr/preview/mmwrhtml/mm5545a1.htm>.
4. Rubenstein LZ, Robbins AS, Josephson KR, Schulman BL, Osterweil D: **The value of assessing falls in an elderly population. A randomized clinical trial.** *Ann Intern Med* 1990, **113**(4):308-316.
5. Sattin WR: **Falls among older persons: A public health perspective.** *Annu Rev Publ Health* 1992, **13**:489-508.
6. Province MA, Hadley EC, Hornbrook MC, Lipsitz LA, Miller JP, Mulrow CD, Ory MG, Sattin RW, Tinetti ME, Wolf SL: **The effects of exercise on falls in elderly patients. A preplanned meta-analysis of the FICSIT Trials.** *JAMA* 1995, **273**(17):1341-1347.
7. Pina IL, Daoud S: **Exercise and heart failure.** *Minerva Cardioangiol* 2004, **52**(6):537-546.
8. Ostenson CG, Bavenholm P, Efendic S: **Exercise is an effective weapon in the fight against type 2 diabetes.** *Lakartidningen* 2004, **101**(49):4011-4012, 4014-4015. Review.

9. Audebert H, Haberl RL: **Secondary prevention after stroke: healthy life style, oral anticoagulation.** *MMW Fortschr Med* 2003, **26**:145(Suppl 2):61-64.
10. Borjesson M, Dahlof B: **Physical activity has a key role in hypertension therapy.** *Lakartidningen* 2005, **102**(3):123-124, 126, 128-129.
11. Asikainen TM, Kukkonen-Harjula K, Miilunpalo S: **Exercise for health for early postmenopausal women: a systematic review of randomised controlled trials.** *Sports Med* 2004, **34**(11):753-778.
12. Bonnefoy M, Cornu C, Normand S, Boutitie F, Bugnard F, Rahmani A, Lacour JR, Laville M: **The effects of exercise and protein-energy supplements on body composition and muscle function in frail elderly individuals: a long-term controlled randomized study.** *Br J Nutr* 2003, **89**(5):731-739.
13. Rockwood K, Howlett SE, MacKnight C, Beattie BL, Bergman H, Hebert R, Hogan DB, Wolfson C, McDowell I: **Prevalence, attributes, and outcomes of fitness and frailty in community-dwelling older adults: report from the Canadian study of health and aging.** *J Gerontol A Biol Sci Med Sci* 2004, **59**(12):1310-1317.
14. Melzer I, Benjuya N, Kaplanski J: **Effect of physical training on postural control of elderly.** *Harefuah* 2005, **144**(12):839-844.
15. Hue OA, Seynnes O, Ledrole D, Colson SS, Bernard PL: **Effects of a physical activity program on postural stability in older people.** *Aging Clin Exp Res* 2004, **16**(5):356-362.

16. Sihvonen SE, Sipilä S, Era PA: **Changes in postural balance in frail elderly women during a 4-week visual feedback training: a randomized controlled trial.** *Gerontology* 2004, **50**(2):87-95.
17. Gillespie LD, Gillespie WJ, Robertson MC, Lamb SE, Cumming RG, Rowe BH: **Interventions for preventing falls in elderly people.** *Cochrane Database Syst Rev* 2001, **3**:CD000340.
18. Wolf SL, Barnhart HX, Kutner NG, McNeely E, Coogler C, Xu T: **Reducing frailty and falls in older persons: an investigation of Tai Chi and computerized balance training.** *J Am Geriatr Soc* 1996, **44**:489-497.
19. Li FZ, Harmer P, Fisher KJ, McAuley E, Chaumeton N, Eckstrom E, Wilson NL: **Tai Chi and fall reductions in older adults: A randomized controlled trial.** *J Gerontol A Biol Sci Med Sci* 2005, **60**(2):187-194.
20. Lord SR, Castell S, Corcoran J, Dayhew J, Matters B, Shan A, Williams P: **The effect of group exercise on physical functioning and falls in frail older people living in retirement villages: a randomized, controlled trial.** *J Am Geriatr Soc* 2003, **51**:1685-1692.
21. Means KM, Rodell DE, O'Sullivan PS: **Balance, mobility, and falls among community-dwelling elderly persons: effects of a rehabilitation exercise program.** *Am J Phys Med Rehabil* 2005, **84**:238-250.
22. Barnett A, Smith B, Lord SR, Williams M, Baumann A: **Community-based group exercise improves balance and reduces falls in at-risk older people: a randomized controlled trial.** *Age Ageing* 2003, **32**:407-414.

23. McMurdo ME, Millar AM, Daly F: **A randomized controlled trial of fall prevention strategies in old peoples' homes.** *Gerontology* 2000, **46**(2):83-87.
24. Reinsch S, MacRae P, Lachenbruch PA, Tobis J: **Attempts to prevent falls and injury: a prospective community study.** *Gerontologist* 1992, **32**:450-456.
25. Wolf SL, Sattin RW, Kutner M, O'Grady M, Greenspan AI, Gregor RJ: **Intense Tai Chi exercise training and fall occurrences in older, transitionally frail adults: a randomized, controlled trial.** *J Am Geriatr Soc* 2003, **51**:1693-1701.
26. Berg WP, Alessio HM, Mills EM, Tong C: **Circumstances and consequences of falls in independent community dwelling older adults.** *Age Ageing* 1997, **26**(4):261-268.
27. Nashner LM: **Adapting reflexes controlling the human posture.** *Exp Brain Res* 1976, **26**:59-72.
28. Nashner LM: **Fixed patterns of rapid postural responses among leg muscles during stance.** *Exp Brain Res* 1977, **30**(1):13-24.
29. Nashner LM: **Balance adjustments of humans perturbed while walking.** *J Neurophys* 1980, **44**(4):650-663.
30. Wolfson L, Whipple R, Derby C, Judge J, King M, Amerman P, Schmidt J, Smyers D: **Balance and strength training in older adults: intervention gains and Tai Chi maintenance.** *J Am Geriatr Soc* 1996, **44**(5):498-506.
31. Oddsson LIE, Boissy P, Melzer I: **How to Improve Gait and Balance Function in Elderly Individuals – Compliance with Principles of Training. Academic Literature Review.** *European Review of Aging & Physical Activity* 2007, **4**:1813-1861.

32. Mansfield A, Peters AL, Liu BA, Maki BE: **A perturbation-based balance training program for older adults: study protocol for a randomised controlled trial.** *BMC Geriatr* 2007, **31**:7-12.
33. Rogers MW, Johnson ME, Martinez KM, Mille ML, Hedman LD: **Step training improves the speed of voluntary step initiation in aging.** *J Gerontol A Biol Sci Med Sci* 2003, **58**(1):46-51.

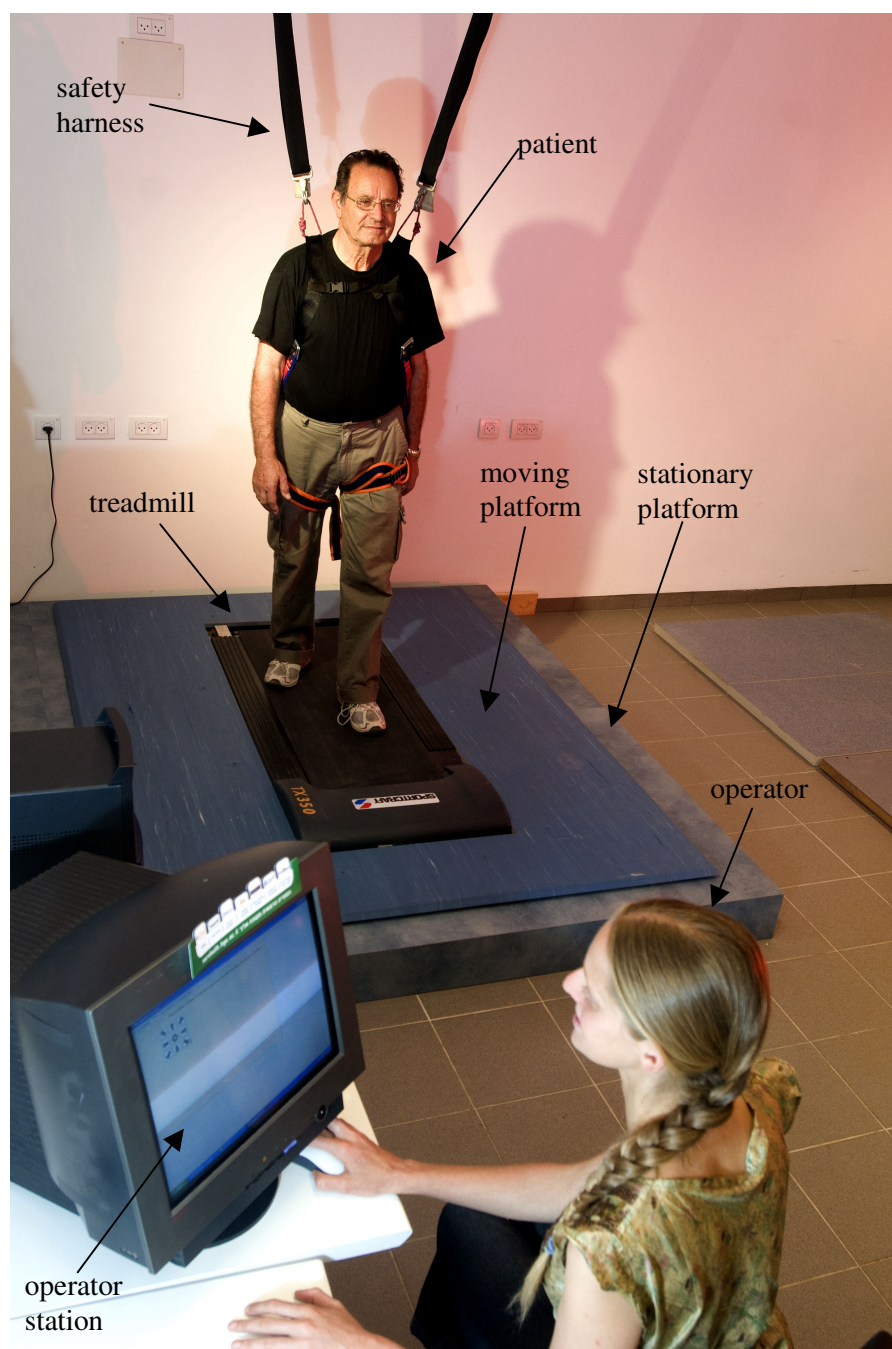


Figure 1: The BaMPer system

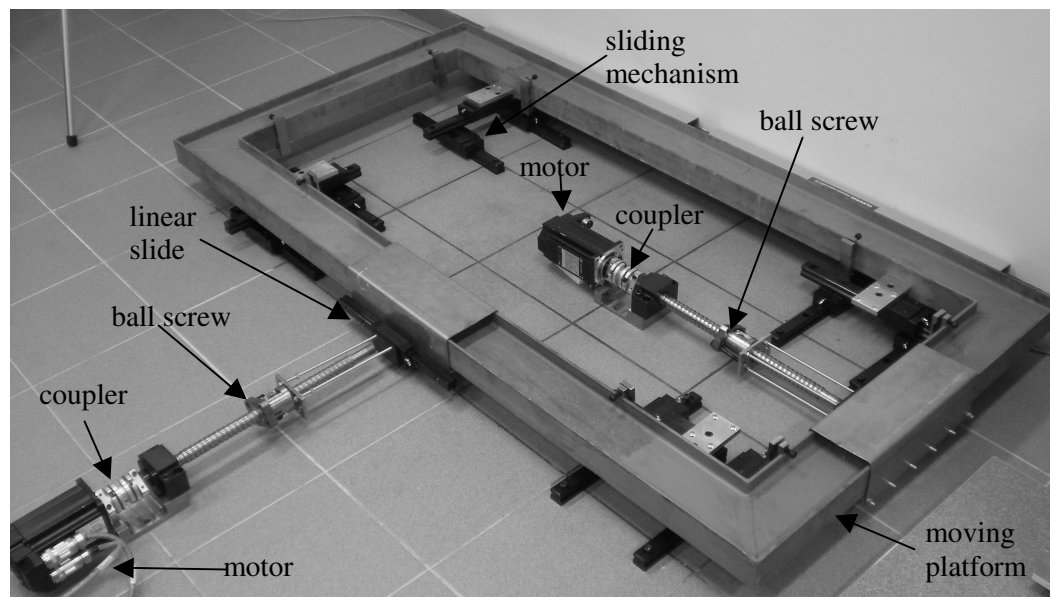


Figure 1: The uncovered driving mechanism of the BaMPer system.

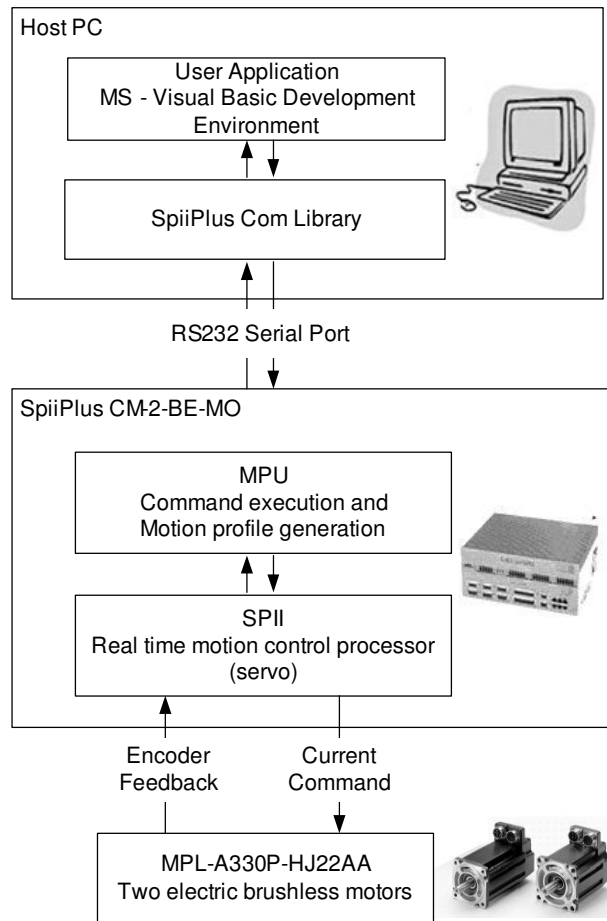


Figure 1: Motion control diagram

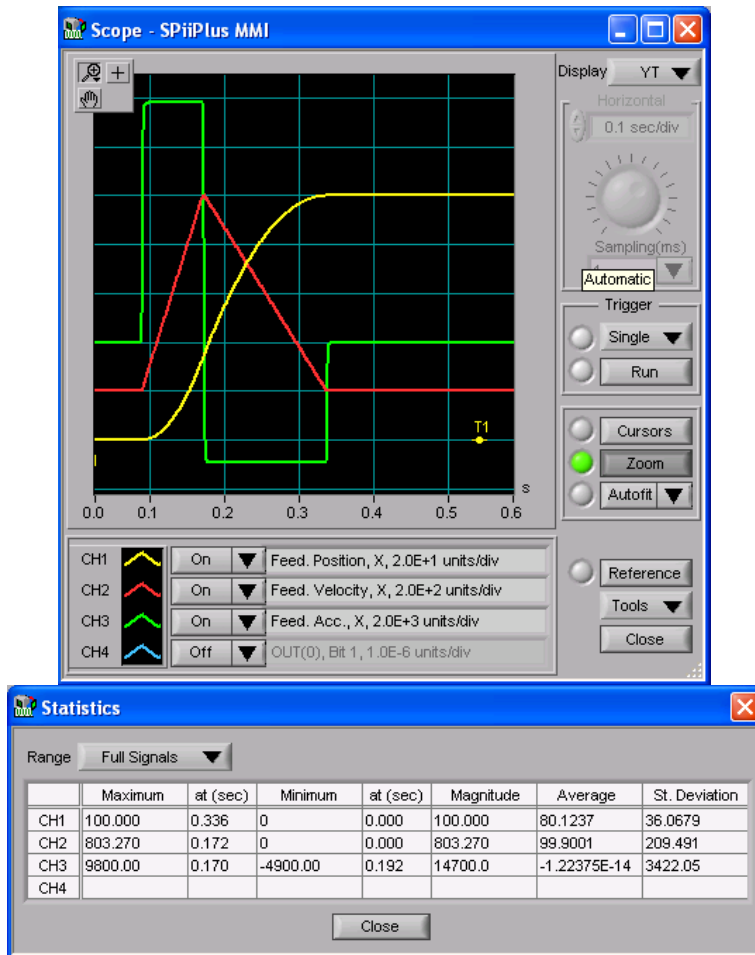


Figure 1: Motion parameters during experiment, all units are in mm and sec.

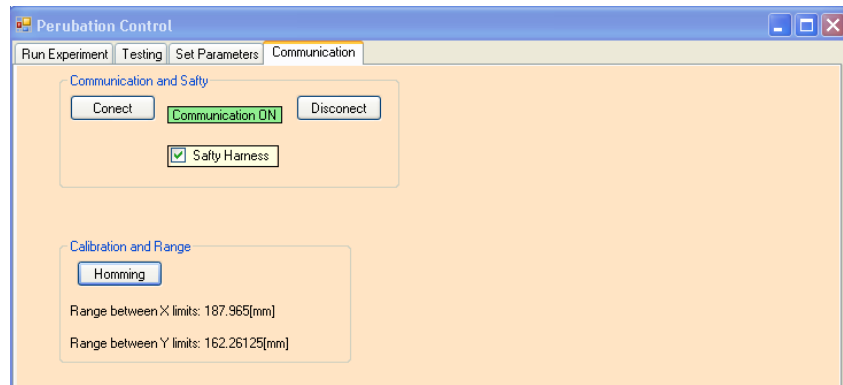


Figure 1: The communication tab of the perturbation control program.

	Min	Max	Current Parameter
Velocity:	60	80	Label2
Acceleration:	5000	10000	Label1
Deceleration	5000	10000	Label1
KillDeceleration:	5000	10000	Label1
Jerk:	5000	10000	Label1
Range:	140	160	Label1
Delay:	3	3	Label1
Number Of Pertubations:	3		

Figure 1: The parameter setting tab of the perturbation control program

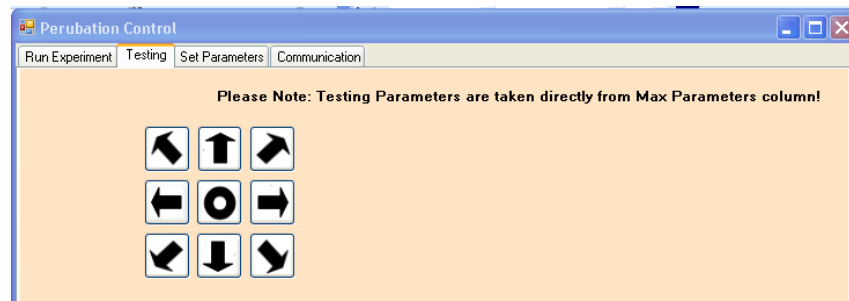


Figure 1: The testing tab of the perturbation control program.

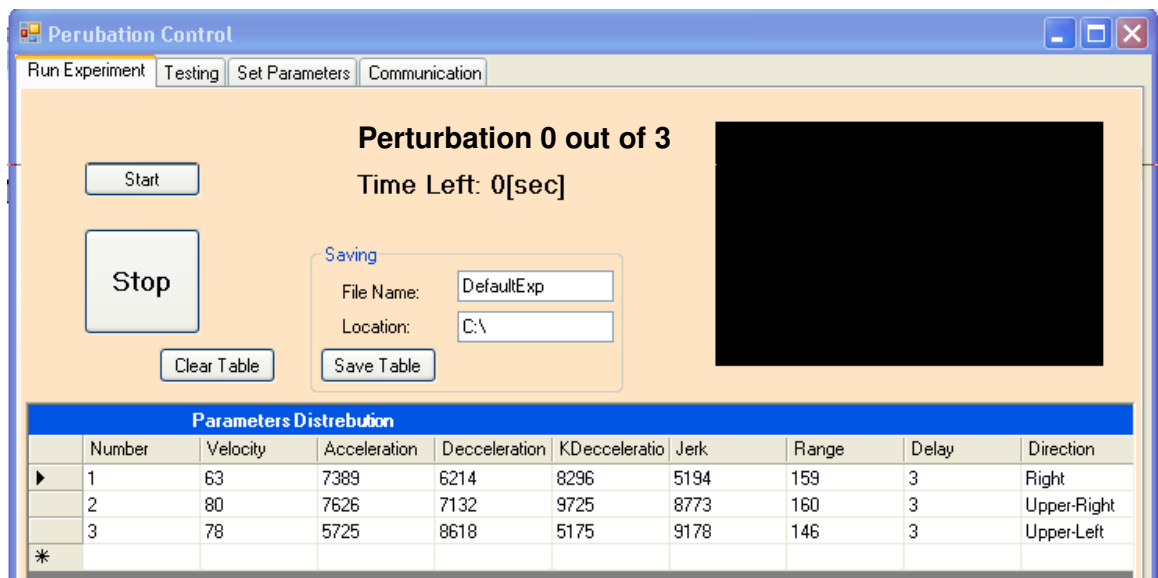


Figure 1: The experiment run or the training tab of the perturbation control program